SENSORS FOR RADIOSONDE USE

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THESIS

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by

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ABSTRACT

Current Navy expendable radiosonde sensors do not meet the required accuracies. A study was conducted to find improved sensors for temperature, pressure and humidity. Recent developments were investigated and recommendations made. An evaluation was conducted on a new humidity sensor and a new pressure sensor. The results obtained indicate improvements but further development is required.

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I. INTRODUCTION

The sensors used in present balloon-borne radiosondes cannot provide the required accuracy up to heights of 100,000 feet. Much work has been done on trying to develop suitable sensors to give these required accuracies.

The measurement of temperature, pressure and humidity is required with the following accuracy:

Temperature	± 0.2^{o} C
Humidity	± 0.3 %
Pressure	± 0.2 mb

The present system used by the Navy with AN/AMT-4B and AN/AMT-11C radiosondes require slow ascent rates due to the relatively slow response rates of the sensors in use and the long interval between samples. These slow ascent rates introduce an error in the soundings due to a non-vertical profile caused by prevailing winds.

If sensors with the required response time can be found, and by using digital techniques, the required accuracies may be met at a much faster ascent rate, thus reducing the non-vertical error.

Current sondes use a baroswitch arrangement to indicate pressure and as a switch to read humidity, temperature and a reference output. The pressure sensor is an integral part of the baroswitch and consists of a simple aneroid cell which distends and moves a contact arm across a 150 segmented commutator bar as pressure decreases. Pressure is determined by counting the number of contacts passed and reference to a factory calibrated chart for each individual instrument. In the present system where the baroswitch cycles between humidity, temperature and reference readings, there is no continuous flow of data from any one sensor. With the advent of digital techniques, the baroswitch may be replaced by a more accurate sensing device and continuous readings taken on all sensors. Such a direct reading device is under development and is evaluated in Section VI.

The current temperature sensor is a ceramic-resistor type with a negative temperature coefficient. Accuracy depends on the ratio of the element's resistance at one temperature to that at another, not on absolute resistance. Long time constants and susceptability to solar effects along with inaccuracies at low temperatures seem to be the main disadvantages.

The humidity elements presently in use are an electrolytic-type resistor consisting of a lithium chloride coated plastic strip (AMT-11C) and a carbon-coated plastic strip (AMT-4B). Neither of these elements has the necessary range, sensitivity and response speeds to meet the required 0.3% accuracy, particularly in the low temperature ranges found at high altitudes. Both types of sensors indicate an erroneous reading after passing through a level of very high humidity; i.e., rain clouds.

An extensive search was conducted, particularly in the humidity sensor region, to find improved types of sensors that have the desired sensitivity, response time, range, and yet be low enough in cost to be practical for large quantities of expendable radiosonde observations.

II. HUMIDITY SENSORS

There are four basic classes for measuring humidity: psychrometry, dew-point hygrometry, electric hygrometry, and spectroscopic hygrometry.

A. PSYCHROMETRY

This method of water-vapour measurement is one of the oldest and most commonly used for stationary readings. In addition to the standard wet-dry bulb system there are various ways wicking may be applied to thermocouples and resistance thermometers. By heating the air sample, the temperature of the psychrometer may be maintained above freezing without changing the indication of vapour pressure. The main disadvantage to this method is the large amount of power required to heat the air sample.

B. DEW POINT HYGROMETRY

The dew- or frost-point measurements are obtained by cooling a surface exposed to the air under test to such a temperature that a deposit of liquid water, or of ice, is in equilibrium and is neither growing nor evaporating. The temperature of the surface is measured by a thermistor embedded below the surface. This temperature is the dew or frost temperature, by definition. The deposit is either detected optically, by conductivity of the cooling surface, or by other means.

The optical detection system, when used with radiosondes, is by necessity an automatic detection system. One such method involves the continuous cooling or heating of a mirrored surface. In the absence of a deposit of moisture the temperature of the surface decreases until a deposit is formed. This may be detected by a photo-electric device and used to control the surface temperature at the dew- or frost-point. There are primarily two methods for achieving this. The first is to provide a liquid heat sink, which supplies a low temperature to the mirror surface, and a heater winding near the surface allowing the fine control necessary to maintain the dew- or frost-point. This technique is shown in Fig. 1. One such system is under development by Cambridge Systems under contract to AFCRL. In the final report [4], the system was found to have a typical response time of 10 seconds for 63% of a step change in humidity. The accuracy of the instrument is $\pm 2^{o}$ C for frost points between -40^{o} C and -60^{o} C. The complete package weighs 1800 grams. The long response time, large physical size, and weight make this system unacceptable for standard Navy expendable radiosonde flights.

The second method involves the use of a thermoelectric heat pump to cool the mirror surface using the Peltier cooling principle. Such a device has the advantage of not requiring a source of cryogenic liquid for the heat sink. The principal involves the use of a thermoelectric junction, constructed of P- and N-type bismuth telluride elements. The mirror assembly is the cold junction and a heat exchanger is used to dissipate the heat at the hot junction.

A control amplifier is used to control the amount of current flowing through the junction and maintains the mirror surface at the dew- or frost-point. The main disadvantage of the thermoelectric type for radiosonde use is the low voltage, high current requirements of the thermoelectric junction.

Another promising method in the field of thermoelectric devices is the measurement of the conductivity of the cooling surface. The controlled dew spot consists of a thin dielectric surface which may be glass, plastic, or various materials. The current flow across the surface of even an excellent insulator is a function of the water density and increases with an increase in water density. The advantage of the conductivity approach over the photo-electric one is that the variation in conductivity is continuous over ranges above and below the dew temperature. The dew-point conductivity may be found for various types of materials and used as a reference in a differential amplifier to control a thermoelectric device.

One last method of dew-point hygrometry uses the alpha radiation hygrometer. A radioactive foil, in conjunction with an alpha particle detector, is mounted on the cold junction of a thermoelectric cooler. If the cold junction is at the dew- or frost-point temperature, condensation will occur, reducing the energy of alpha particle emission. A second foil is mounted with a control layer absorber between the foil and a second alpha particle detector. The difference between these two detectors is used in a feedback amplifier to control the thermoelectric element. One advantage of the alpha radiation method is that the energy attenuation of alpha particles is the same for equal mass deposits of water or any of the crystalline forms of ice; the sensitivity of detection remains constant for any water state.

These systems appear to be very promising as far as accuracy, speed of response and range are concerned. The main barrier for use of these methods is the cost of the units for routine radiosonde flights.

C. ELECTRIC HYGROMETRY

This method of measuring moisture includes both the lithium-chloride and carbon elements which are used in current Navy radio-sondes. Neither of these devices meet the required accuracies. There are a number of promising developments in the field of electric hygrometry.

1. Aluminum Oxide Humidity Element

The aluminum oxide humidity element consists of a base of aluminum, an oxide made by anodizing the base material, and an evaporated conductive coating of metal (see Fig. 2). Elements under consideration are of the Stover [5] type. Details of cell construction and manufacture are described in the Stover article. Changes in humidity cause the impedance of the cell to change. One manufacturer claims rapid response time, small temperature coefficient, no hysteresis effects, and no permanent effects after being immersed in water.

An evaluation of the aluminum oxide element was conducted by Brousaides [6]. Twenty-four elements were tested over a temperature and humidity range of + 30^{o} to - 50^{o} C and 20 to 95 percent relative humidity. The response time lag of several sensors to step-function humidity changes was also examined at temperatures of + 25^{o} and - 30^{o} C.

The results of the evaluation are very poor. Hysteresis was found to give an error of up to 25 percent, response time lags of up to 500 seconds at - 30^{0} C were measured, and a considerable temperature coefficient was observed.

From this evaluation, the aluminum oxide sensor in its present state is unacceptable for radiosonde applications. Further research on this device is indicated.

2. Barium Fluoride Humidity Element

The barium fluoride humidity sensor (Fig. 3), developed at the National Bureau of Standards by Jones [7], consists of a glass substrate on which a film of barium fluoride has been deposited by vacuum evaporization over closely spaced metallic film electrodes. The resistivity of the sensor varies inversely with relative humidity by physical absorption of water vapor. The thin film of barium fluoride, 0.3 microns thick, indicates a fast response time to a step input of relative humidity.

Ten flights in radiosondes were made by Jones using these elements with a companion radiosonde carrying the conventional lithium chloride humidity element. Results of these flights and laboratory testing indicate changes of relative humidity of 1.5 to 100 per cent in the temperature range of 30 to - 60^{0} C. Exposure to high humidity and passage through precipitation had no apparent effect on the elements. The average response times (63 percent change) to a step input of increasing relative humidity for the barium fluoride element are approximately 0.1 seconds at room temperature, 1 second at - 20^{0} C, and 3 seconds at - 40^{0} C. Corresponding values for the conventional lithium chloride element are 3 seconds at room temperature, approximately 50 seconds at - 20^{0} C, and 480 seconds at - 40^{0} C. The median of the hysteresis values was approximately 1.5 percent relative humidity in the temperature range 40^{0} C to - 40^{0} C. A considerable drift in calibration with storage time was found to occur from contamination of the elements by diffusion pumping fluid in the production process. Modified procedures in the diffusion process should eliminate this effect and further testing is indicated in the storage stability area.

Two barium fluoride elements were obtained and are evaluated in Section V.

3. Polyelectrolyte Electrical Resistance Humidity Element

The polyelectrolyte humidity element has a polystyrene base with an overlay of silver electrodes. The blanks are sprayed with a hydrophilic film suspension of cross-linked polystyrene sulfonic acid particles. In the polyelectrolyte element, variation of resistance with relative humidity depends on the varying conduction of ions within a film. The sensitivity of the element (10^{2} to 10^{8} ohms) allows small changes in relative humidity to be observed. Response times for a 63 percent change are approximately 1.4 seconds at 25^{0} C and 32 seconds at - 40^{0} C. Hysteresis effects indicate a mean difference in relative humidity of 2.7 percent between 30 and 70 percent relative humidity at 25^{0} C. The element stability with time indicates further study into the aging characteristics. After 3 months time the elements read only 75 to 80 percent of their initial value.

All three of these devices show great promise in improving the sensitivity, step response, and range required in routine radiosonde weather observations. However, further development is required if they are to meet the required accuracies.

D. SPECTROSCOPIC HYGROMETRY

This method of measuring humidity is fundamentally an optical instrument designed to measure the absolute humidity of the atmosphere by measuring the absorption of radiant energy by water vapor over a given optical path. It is a passive method of measuring water vapor density without disturbing the air sample, while the methods discussed previously are essentially active. The instrument measures water vapor density below freezing and avoids the ambiguity of the vapor pressure being sampled over ice or supercooled water.

With the advent of solid state devices, much progress has been made in this field. Since most such devices are still in the development field, only one type will be mentioned.

1. The Lyman-Alpha Humidiometer

The Lyman-Alpha Humidiometer uses the absorption of radiant energy at 1.2156 microns by water vapor to measure directly the water vapor density of the air. The instrument consists of a hydrogen lamp radiating across a sampling path to a nitric oxide detector through lithium fluoride windows. This radiation is detected by photo-ionization, which causes a current to flow in the associated circuitry. The amount of current is a function of the water vapor density in the measuring path and may be converted to a direct readout or a signal suitable for radiosonde usage. This method has the advantage of measuring the water vapor content without disturbing the air sample and a superior accuracy at low moisture content due to the high water vapor absorption coefficient at this wavelength. The sensitivity and response times of this instrument are very good.

There are various other instruments under development utilizing the absorption of water in the ultraviolet and infrared bands which show promise. In the present state of development, none of these devices can be considered for a low cost, expendable radiosonde system.

III. TEMPERATURE SENSORS

The accuracy and speed of response of the temperature sensor is a prime factor in the accuracy of readings taken on radiosonde flights. The oscillator frequency in the transmitter will vary in frequency as a function of temperature due to the electronic components involved. This drift may be compensated for if the temperature is known accurately. Also certain types of pressure and humidity elements are temperature sensitive.

There are primarily two types of temperature sensors used in radiosondes, resistance thermometers and thermistors. Resistance thermometers can be constructed in any size and hence may have time constants ranging from fractions of seconds to minutes. The sensors with fast time constants, however, are fragile and susceptible to errors from contamination by exposure to air from dirt, moisture, etc.

The advantages of thermistors over resistance thermometers are their high temperature coefficient and relatively small size. Thermistor beads from 0.006 to 0.1 in. are available commercially. They are physically rugged, have high sensitivity, fast response times, and are highly accurate.

There has been a great deal of research in thin film sensors in order to increase the speed of response. However, because of their larger size, solar and radiation effects becomes more pronounced. One company is experimenting with thermistor material vacuum deposited on a 0.25 mil mylar base. The mylar is supported to expose both surfaces. The response time of this sensor is good, but further work is being done to improve the temperature coefficient of resistance of the semiconductor material.

Another new thin film sensor has been developed with a germanium sensitive layer, silicon monoxide dielectric coating and aluminum reflective coating on a 0.3 mil substrate. The time response is in the order of half a second, but the sensitivity is slightly lower than that of the bead thermistor.

In order to obtain the desired accuracy and response time, thin film thermsistor sensors deposited on substrates of material with high thermal dissipation capacity are desired. Further research in this field is indicated because of the dependence on temperature of the complete radiosonde system.

IV. PRESSURE SENSORS

A. GENERAL

The aneroid baroswitch used on current radiosondes is inaccurate and does not provide continuous pressure information. With the advent of digital techniques, the baroswitch may be eliminated and the aneroid barometer replaced by a direct reading pressure sensor with the required accuracy.

There are a large number of devices that may be used to measure pressure from approximately one millibar to atmospheric pressure. Since most of these devices have no applications for radiosonde usage they will not be discussed.

B. ANEROID CELLS

The aneroid cell is a mechanical diaphragm device that must have its mechanical displacement converted to electrical signals for radiosonde applications. There appears to be no great difficulty in construction of aneroid cells capable of achieving the required accuracy of ± 0.2 mb at lower altitudes. The cost for an expendable unit that would meet the accuracy required to altitudes of 100 thousand feet would be excessive.

C. HYPSOMETERS

The hypsometer method of measuring pressure utilizes principles based on thermal conductivity, absorption of radiation, and the boiling temperature of pure fluids. The hypsometer is relatively simple in construction and has a large dynamic range.

The basic hypsometer consists of a source of vapor and a sensor to detect the vapor equilibrium temperature which is a function of the pressure. The equilibrium temperature is sensed by a thermistor whose resistance closely approximates the inverse of the pressure.

The principal limitation of this particular design is that it is restricted to applications involving fast changing pressures, as those encountered by a descending sonde. Since the present Navy sonde is primarily a slow ascent device the hypsometer would have more applications in a rocket sonde.

D. SEMICONDUCTOR PRESSURE SENSORS

Recent developments in integrated circuit design make the production of small, light-weight, fast-responding, and sensitive pressure transducers technically feasible. Typical diaphragm sensors flex with pressure against mechanical and electromechanical constraints while others carry bonded semiconductor devices piggyback.

In a new semiconductor pressure transducer under development a silicon crystal, 150 microns thick and 270 mm square, senses pressure from one mb to atmospheric pressure. The sensor consists of a single silicon chip with a four-arm-active Wheatstone bridge diffused directly into it (Fig. 4). As the pressure is reduced (below atmospheric), the piezo-resistance effect changes the resistance in the sensor arms of the bridge. Two of the bridge arms are located in a region of tension and two in a region of compression. Tension increases the resistance in an arm; compression reduces it.

Hysteresis effects should be negligible as the bridge circuit is an integral part of the pressure diaphragm, not attached to it.

The low temperatures encountered in the stratosphere may be a serious problem. A property of silicon is that as temperature is decreased its sensitivity increases. In order to make measurements over the range of - 80 to 25^0 C, compensation is required. Some improvement can be obtained by using a constant-current source to drive the sensor. In such a circuit the voltage across the bridge decreases as the resistance decreases with temperature and this decrease in voltage tends to counteract the increase in sensitivity.

Another compensating scheme is to apply a constant voltage source in the arrangement shown in Fig. 5. A thermistor, exposed to the same temperature as the pressure sensor, is placed in one lead of the constant-voltage supply. The thermistor is then shunted by a stable resistance of such a value that the bridge voltage decreases with temperature at the same rate as the sensitivity decreases.

A third method of reducing the temperature effect is to increase the doping level of the Wheatstone bridge material. However care must be taken as to the proper doping level as the sensitivity is decreased with increased doping.

The most economical scheme would be increased doping level and a constant-current source to drive the sensor. Further care must be taken as to the maximum value of current that may be applied. A higher current will increase the level of output but too large a current will lead to excessive ohmic heating and eventually destroy the sensor.

The semiconductor pressure sensor appears to hold the most promise in the development of an expendable, low cost, lightweight, pressure sensor that will meet the required accuracies. One such sensor, weighing 15 grams, is shown in Fig. 6.

V. AN EVALUATION OF THE BARIUM FLUORIDE HUMIDITY ELEMENT

A. GENERAL

Two barium fluoride elements were received from Jones at the National Bureau of Standards for evaluation. These elements were produced using methods which should improve the storage stability of the sensor. Reference 9 explains in detail the methods to reduce contamination of the elements in the vacuum chamber during the process in which the barium fluoride film is deposited. No study on the aging characteristics was conducted due to the late acquirement of these elements. The primary interest was to determine the step response, temperature dependence, and calibration curve for the barium fluoride elements for possible application in routine radiosonde flights.

B. TESTING PROCEDURE

Since dc current causes polarization of the elements, an ac source was needed to measure the resistance. The circuitry used is shown in Fig. 7 and 8. The 100 Hz square wave generator provides the ac current to the element under test. The output of the sensor is developed across a voltage divider consisting of four pairs of front-to-back silicon diodes to obtain a voltage proportional to the logarithm of the sensor resistance. A FET follower was used to match the high impedance of the sensor to the operational amplifier input. In order to obtain a dc output with a fast response time, an operational amplifier with full feedback was used as a charging circuit for the charging capacitor. Since the positive portion of the square wave is not flat at the beginning and end, it was decided to gate the charging circuit during the linear portion of the output. This was accomplished by a delayed pulse generator gating a FET. The output of the gated FET is applied to the charging capacitor, which drives the output FET follower. This follower provides isolation for the charging capacitor and provides a low impedance output. The output is measured by a differential voltmeter or recorded by an analog recorder. The response time for this device was 40 milliseconds for 100% change for a step response of a short-to-open circuit, which is faster than the elements under test.

The test apparatus employed was a Tenney chamber and a closed cylinder in which the element was mounted (Fig. 9). The Tenney chamber was maintained at various temperatures and at different values of relative humidity by aqueous solutions of various salts [11]. When the Tenney chamber reached equilibrium the sample was drawn into the closed cylinder and the relative humidity in the chamber increased or decreased. The element in the closed cylinder was then quickly withdrawn from the cylinder into the air flow of the circulating fan in the Tenney chamber. The time required for the element resistance to change from one humidity to another was recorded on an analog recorder. The response time for the element resistance to change 63% was then calculated from the analog output. The air velocity in the Tenney chamber was approximately one-fourth the typical rise velocity of a radiosonde; thus, the response times acquired are considerably conservative. A typical response curve is shown in Fig. 10. Observed response times are tabulated in Table I for the two elements under test.

A calibration curve for the elements was obtained by placing various values of relative humidity in the chamber at 24^{o} C and measuring the element resistance after the chamber had reached equilibrium. The results of these tests are shown in Fig. 11.

In order to determine the temperature dependence of the elements, desiccant bags were placed in the chamber to maintain the atmosphere close to 0% RH. The Tenney chamber was then cycled between 25 and -80^{o} C. The temperature dependence at 0% RH is shown in Fig. 12.

C. CONCLUSIONS

From the calibration curve it may be seen that both elements have the same characteristics. This is not surprising as they were both from the same batch. The sensitivity of the elements is seen to vary from 10^3 to 10^8. This is highly desirable as it allows small variations in relative humidity to be detected.

Due to the difficulty in maintaining large variations in relative humidity between the chamber and the closed cylinder at temperatures below 0^{o} C, a step response was only obtained in the direction of decreasing relative humidity. The response times found were of shorter duration than those previously reported. This may in part be accredited to the fast response of the AC ohmmeter circuit.

Values of relative humidity from 0 to 98% were recorded. This indicates the wide range of the sensor.

A negative temperature coefficient of resistance was found by testing the element at 0% RH. With resistance at 25° C as reference, the resistance was found to vary 0.144% per degree Centigrade. This temperature effect would not be detrimental in the use of the sensor if it is known for all values of relative humidity. It may be eliminated in data reduction with digital computer techniques.

The basic evaluation of the barium fluoride element shows great promise for its future use in standard radiosonde flights. Its high sensitivity, fast response, and range should greatly enhance the humidity measurements in radiosonde flights.

Further study on the aging characteristics is indicated before the sensor may be used extensively for the large number of expendable radiosonde flights required in daily operations.

VI. AN EVALUATION OF A SEMICONDUCTOR PRESSURE SENSOR

A. INTRODUCTION

Two different types of semiconductor pressure sensors were received for evaluation. The first (Fig. 13) was found to have excessive temperature effects due to the change in pressure of the "air bubble" under the silicon chip with changing temperature. The second sensor was constructed in the same manner as the first with the exception that the "air bubble" was replaced by a "vacuum" to reduce the temperature effects.

B. TESTING PROCEDURE

In order to test the pressure sensor a testing scheme had to be devised to cover the pressure range of 5 mb to atmospheric and a temperature range of - 80 to 25° C.

A Tenney chamber was used to produce the required temperature range. A pressure chamber was manufactured so that it could be inserted into the access hole in the Tenney chamber and still have external controls for changing and reading the pressure. Pressure readings were made with a double column mercury manometer.

The sensor was driven by a constant-current source (Fig. 14) and the current monitored throughout the testing. The voltage output of the sensor was recorded with the aid of a Fluke dc differential voltmeter.

C. RESULTS

Since the first sensor received was found to have excessive temperature effects due to the "air bubble" of 15 psi under the chip, no further evaluation was conducted.

The improved sensor with the vacuum under the silicon chip was tested over the full range of temperature and pressure. The silicon chip is initially flexed inward due to the vacuum and flexes outward towards a stationary position at low values of pressure (5 mb). The Wheatstone bridge is so constructed as to give a maximum output at atmospheric pressure. At room temperature and one atmosphere, with 3 ma of current applied, the full scale output was found to be 102 mV. Figure 15 shows a calibration curve of the sensor at various temperatures. A thermistor was used to monitor the temperature of the sensor to ensure equilibrium conditions. It may be seen from these curves that the output is linear over the entire pressure range. It should be noted that the output reached zero at approximately 730 mm Hg vacuum. This is not the required lower limit of 5 mb and may be caused by an improper vacuum under the diaphragm or by an offset in one or more of the legs in the Wheatstone bridge. By cycling the pressure sensor between its limits it was found that the calibration curves were reproducible and there were no hysteresis effects observed.

A test was conducted on the sensor to determine the value of applied current that would produce heating effects. The sensor was placed in an environment of one atmosphere and ambient room temperature. The constant-current source was varied from 0 to 15 ma and the output voltage recorded (Fig. 16). The output was linear until the current reached approximately 7.5 ma. Thus the sensor should be operated well below this maximum value.

It may be noted from the calibration curves that there is a definite temperature effect on the output characteristics of the sensor. The temperature effect was found to be non-linear. Figure 17 indicates the large amount of error introduced by a change in temperature. At - 80^0 C there is a 13.5% error from the ambient room temperature value of output.

Another effect noted was that the sensor in its present form is susceptible to changes in humidity. The sensor was placed in the Tenney chamber with desiccant bags to produce approximately 0% RH and then exposed to a high value of humidity. The output voltage varied 2.5 mV over this humidity range.

In order to evaluate the response time of the sensor an approximate step of pressure was applied to the sensor at ambient room temperature. This was achieved by vacuum pumping the test chamber down to -760 mm Hg and then opening it suddenly to atmospheric pressure. The output of the sensor was recorded on an analog recorder and found to be 0.136 seconds for 100% change. Since the step function was limited by the size of the valve aperature, this value is very conservative.

D. CONCLUSIONS

The semiconductor pressure sensor shows great promise in attaining the desired accuracies in pressure measurement for expendable radiosonde applications. Further development is required to reduce the temperature-sensitive nature of the sensor. Increased doping levels may reduce the temperature effect and coating of the silicon chip with a non-hygroscopic material should eliminate the effects of humidity.

VII. CONCLUSION

At the present time neither temperature, pressure nor humidity sensors meet the stringent requirements imposed in Section I. There is continued research being conducted in all three fields of sensors.

The advent of thin film sensors should lead to the development of low cost, accurate temperature and humidity sensors. The thin film thermistor sensor with adequate protection against solar and radiation effects appears feasible for highly accurate temperature readings.

The barium fluoride humidity sensor appears to hold great promise. Further development is required in fabricating techniques that will provide uniform sensors that are free of aging effects.

The semiconductor pressure sensor holds great promise for obtaining the required accuracy for pressure measurement. Since the pressure sensor evaluated is still in the development stage, further evaluation is required.

APPENDIX A

TABLE 1.

RESPONSE TIME MEASUREMENTS (63%)

ELEMENT	TEMP.(^{o} C)	FROM % RH	TO % RH	RESPONSE TIME(SEC)
1	25	93	1	0.296
	25	2	98	0.088
	25	11	54	0.072
	25	52	40	0.080
	4	34	1	0.080
	4	1	34	0.432
	4	28	1	0.176
	- 20	19	0	0.536
	- 20	15	0	0.440
	- 40	25	0	1.160
2	25	70	0	0.056
	25	96	0	0.175
	0	67	0	0.520
	- 40	58	0	1.600

APPENDIX B FIGURES

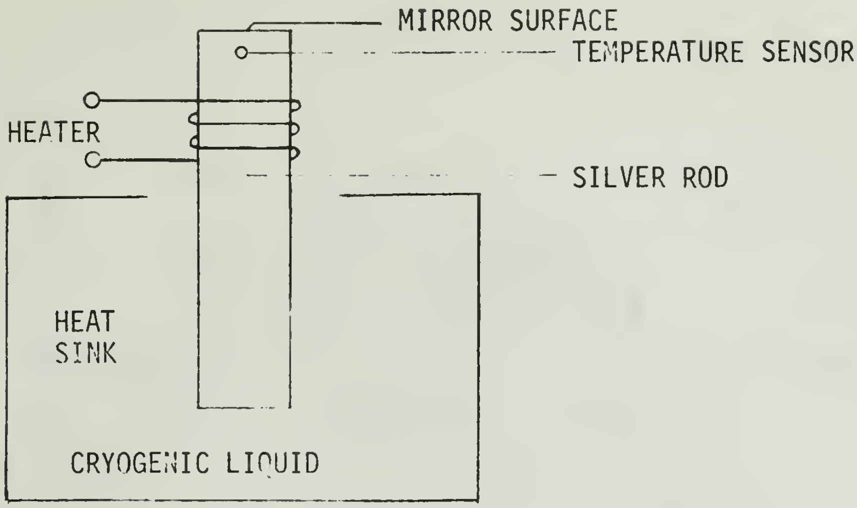

FIG. 1. RESISTANCE HEATER AND LIQUID HEAT SINK

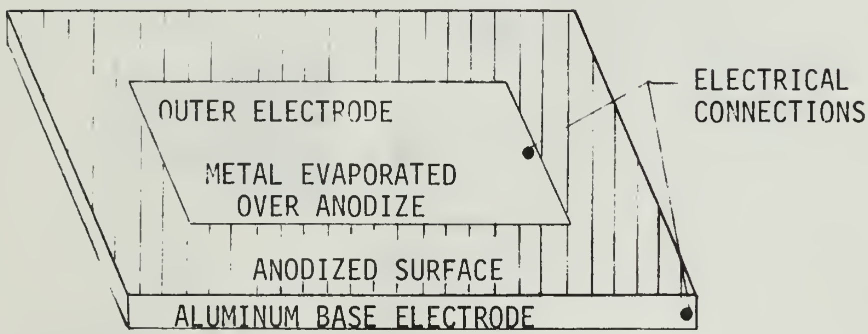

FIG. 2. MECHANICAL CONSTRUCTION

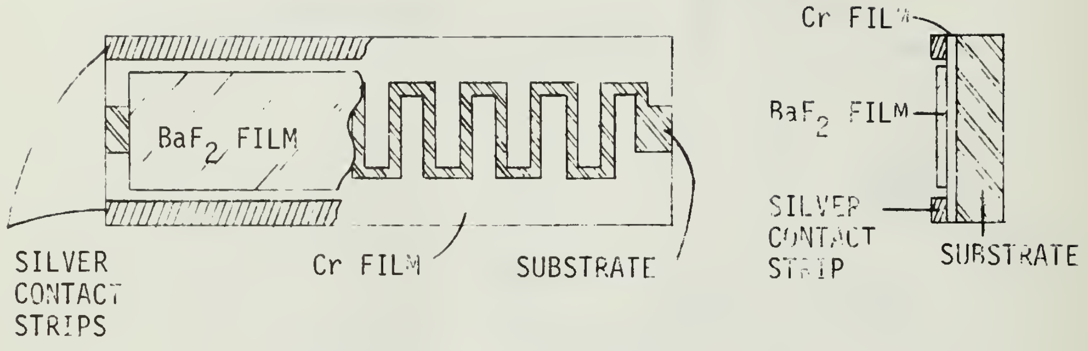

FIG. 3. BARIUM FLUORIDE HUMIDITY ELEMENT

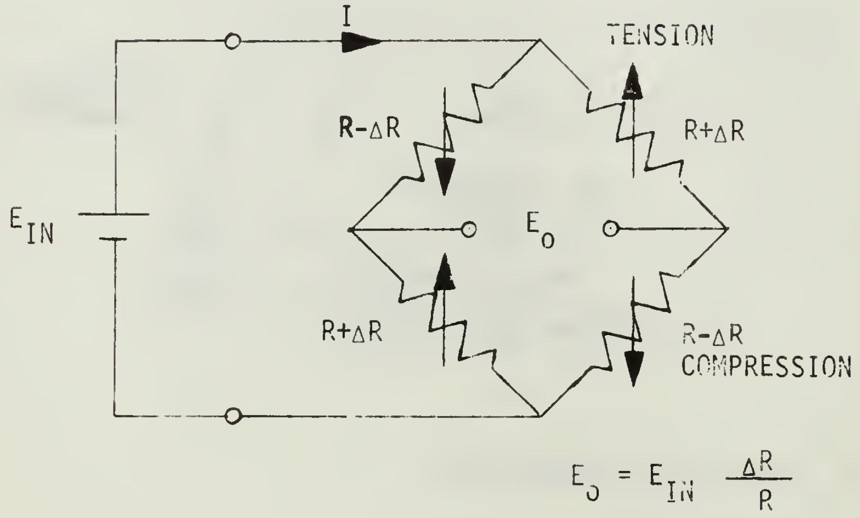

FIG. 4. WHEATSTONE BRIDGE

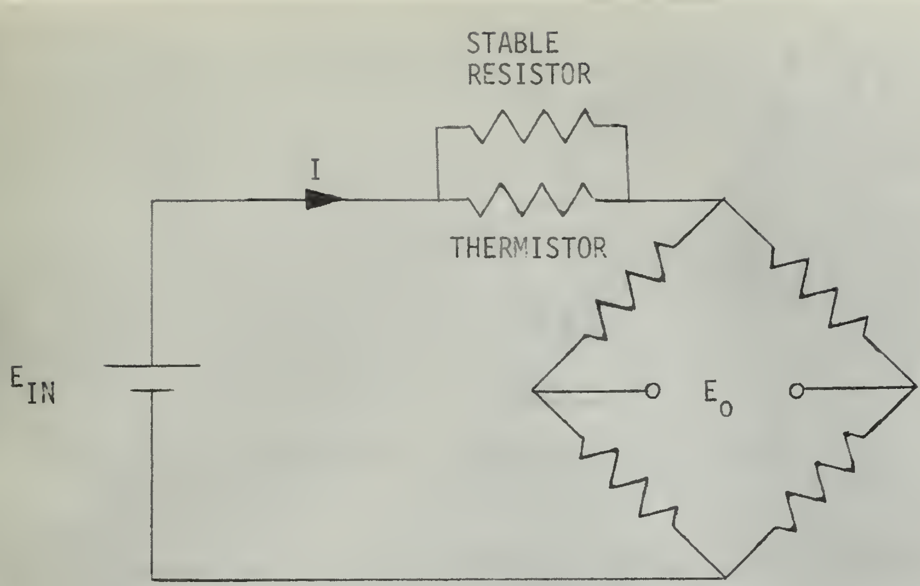

FIG. 5. WHEATSTONE BRIDGE WITH TEMPERATURE COMPENSATION

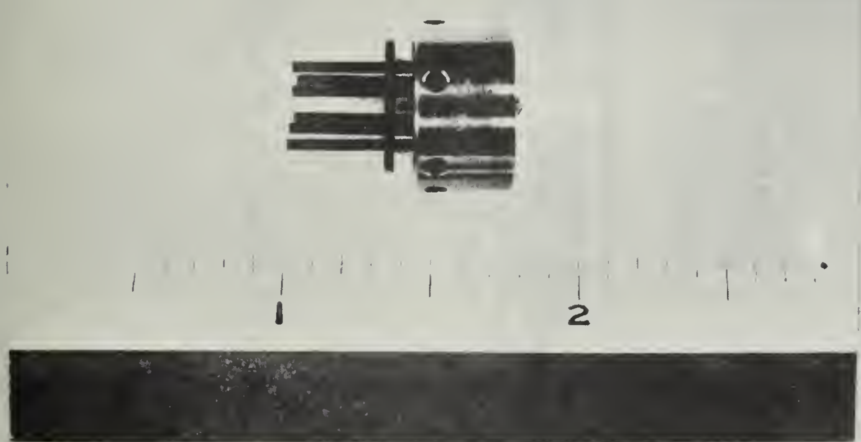

FIG. 6. SEMICONDUCTOR PRESSURE SENSOR

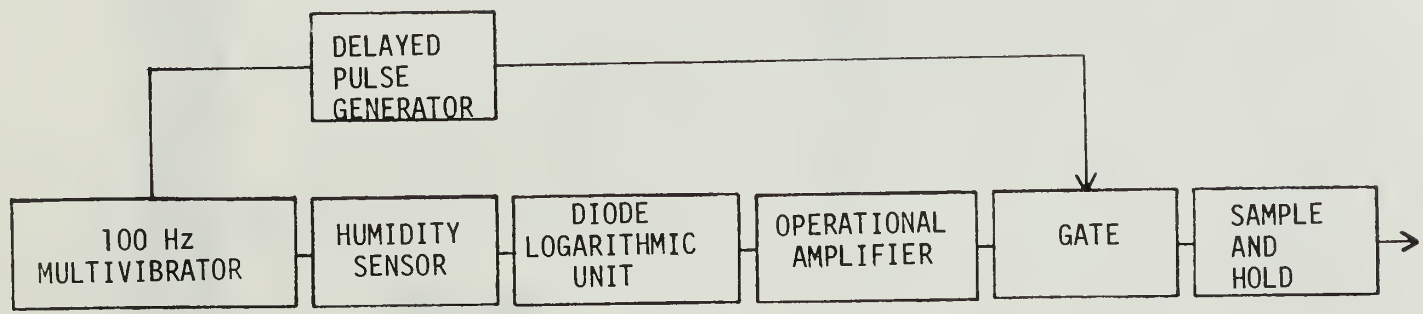

FIG. 7. BLOCK DIAGRAM OF AC OHMMETER

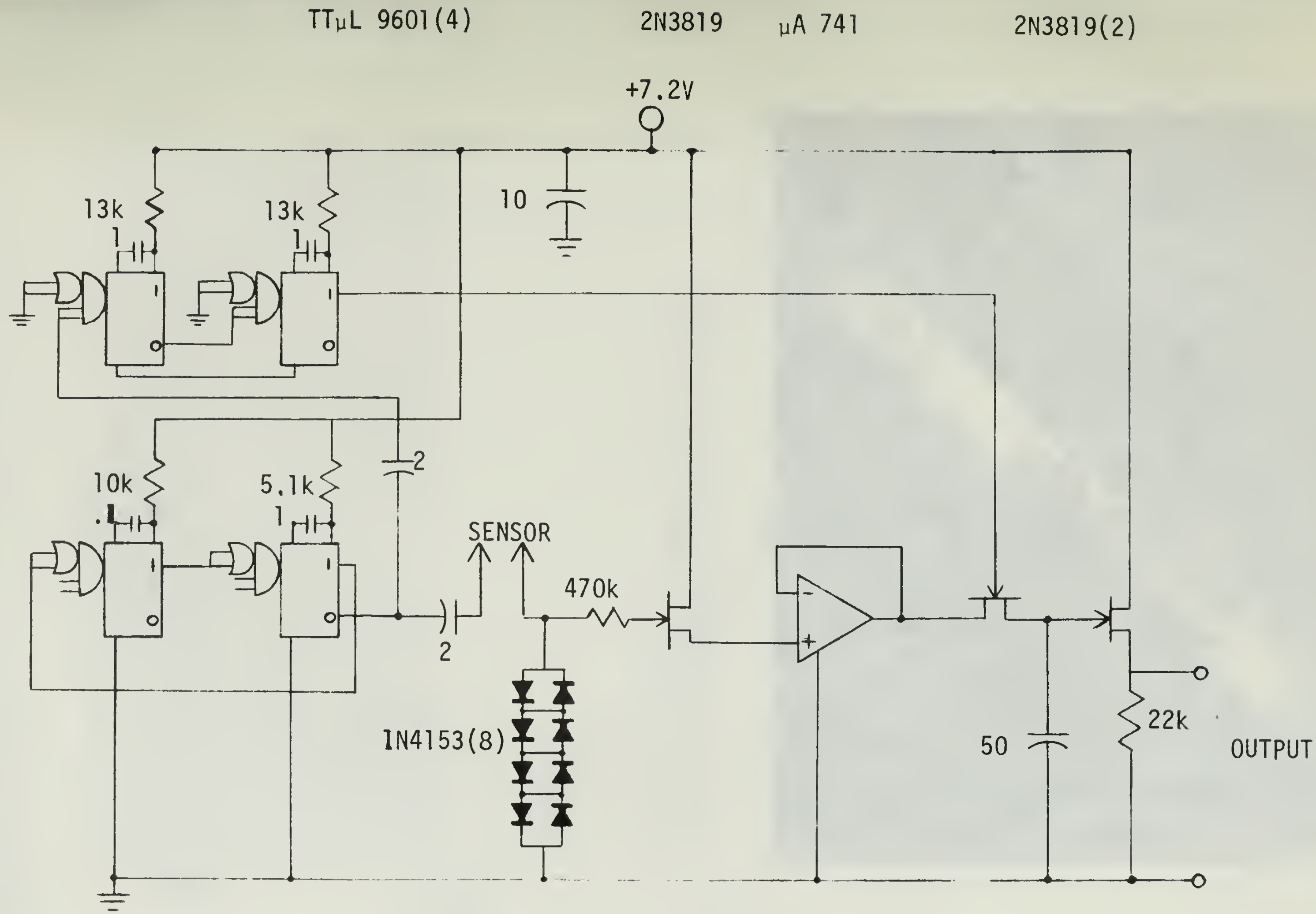

FIG. 8. AC OHMMETER CIRCUIT

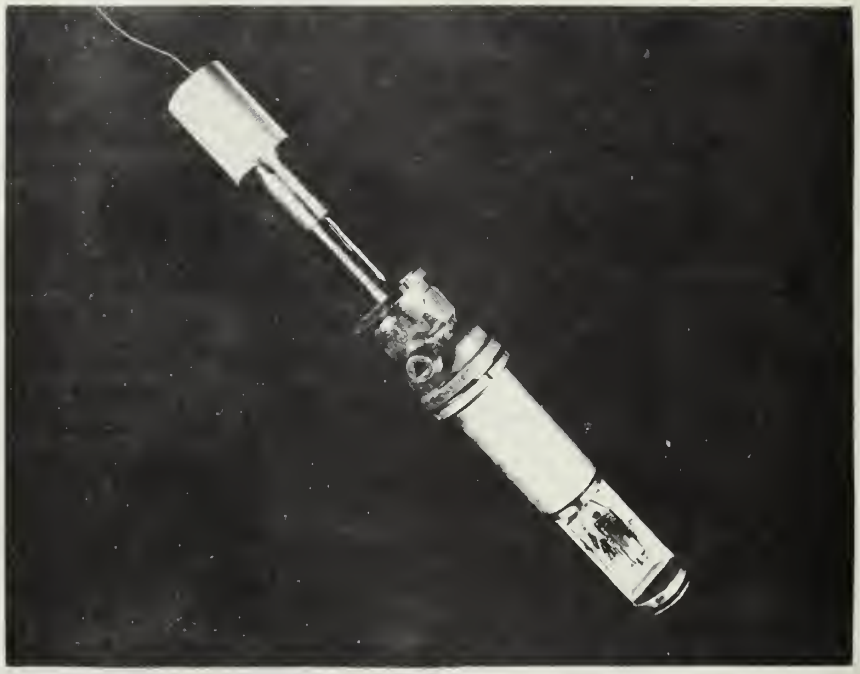

FIG. 9. HUMIDITY SENSOR TEST CYLINDER

FIG. 10. STEP RESPONSE

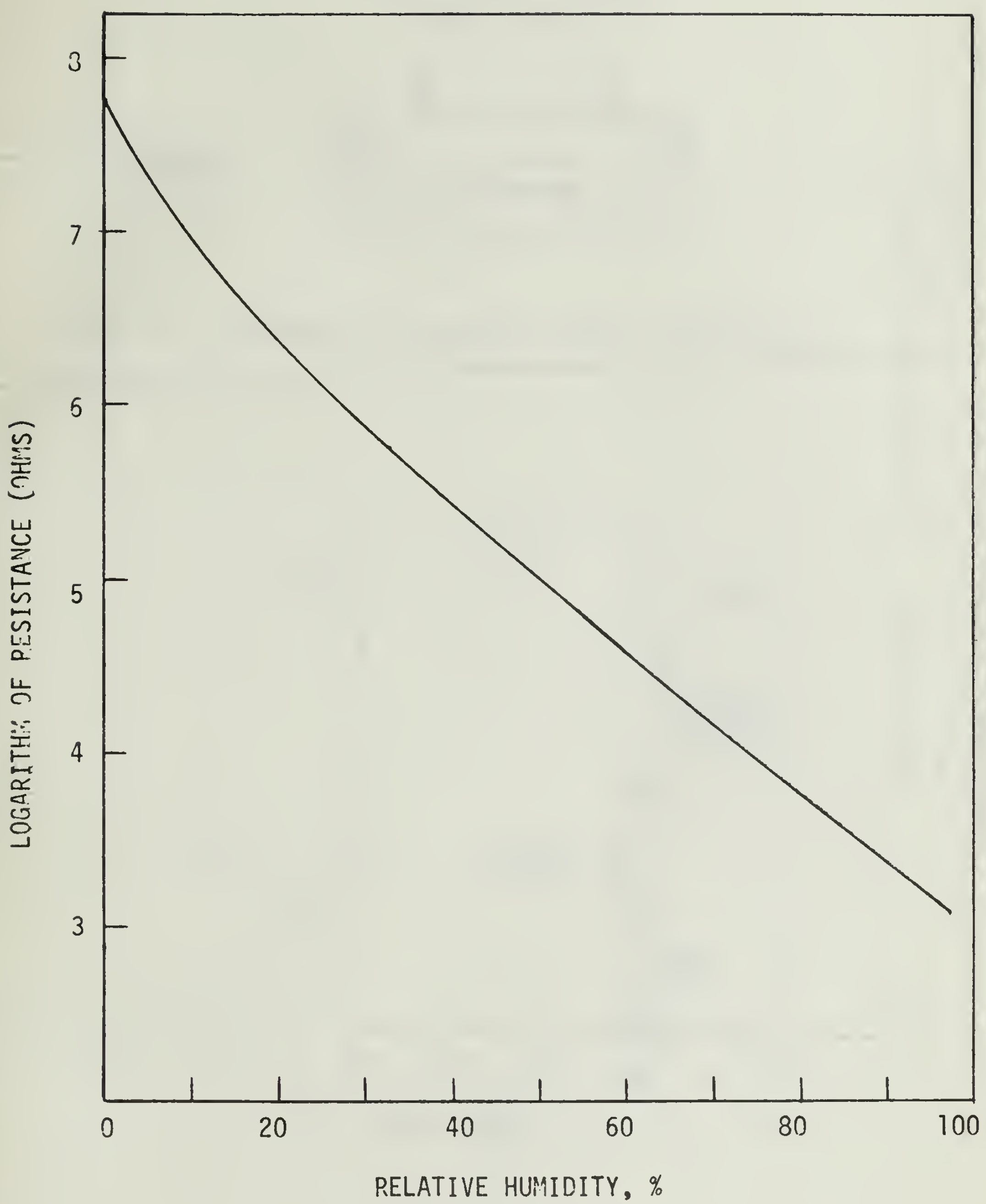

FIG. 11. CALIBRATION CURVE FOR BARIUM FLUORIDE ELEMENT

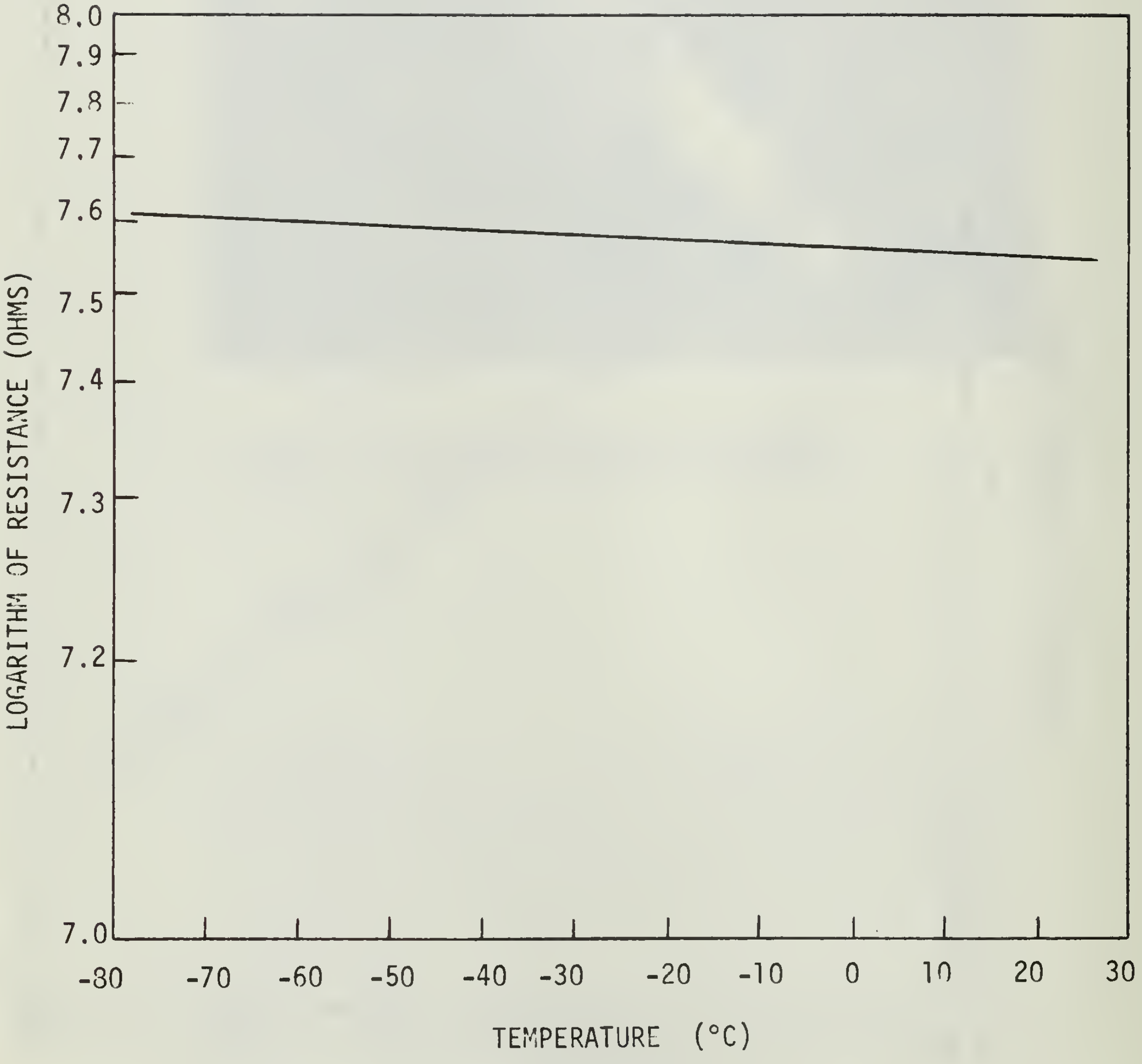

FIG. 12. TEMPERATURE EFFECT AT 0% RH

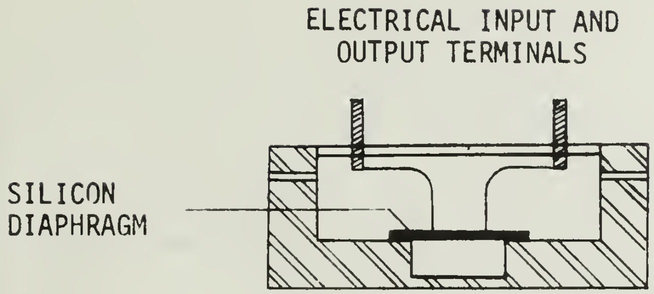

FIG. 13. SEMICONDUCTOR PRESSURE SENSOR CROSS-SECTION

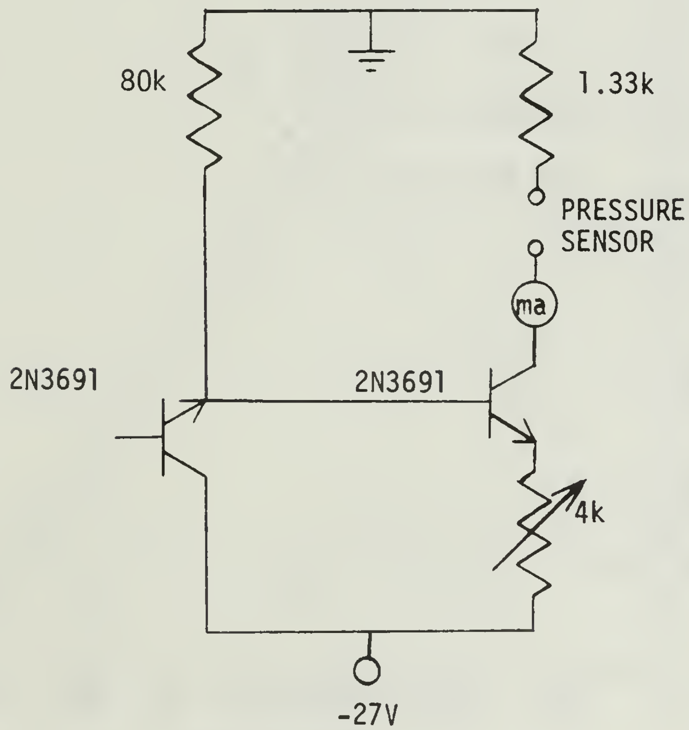

FIG. 14. CONSTANT-CURRENT SOURCE

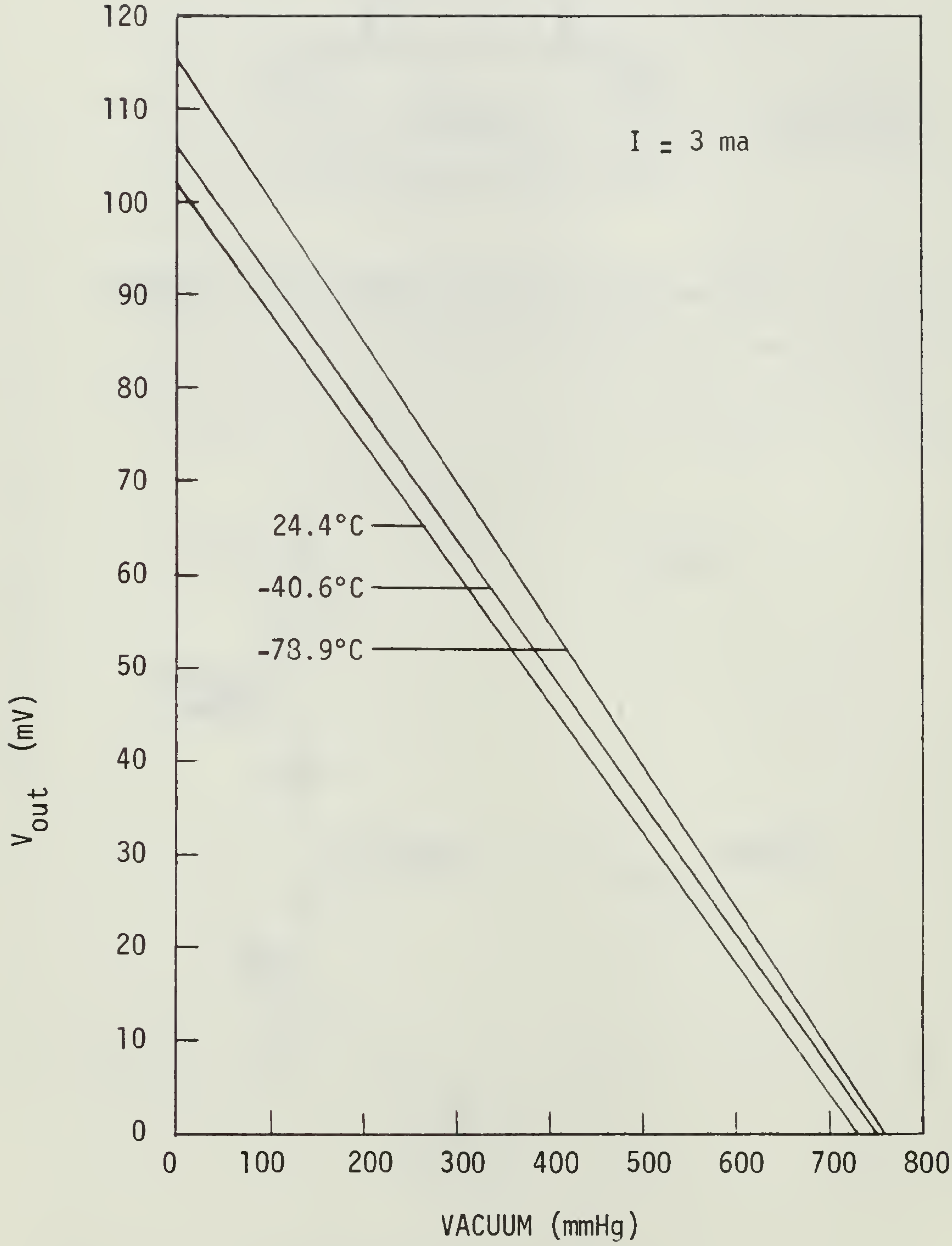

FIG. 15. CALIBRATION CURVES FOR SEMICONDUCTOR PRESSURE SENSOR

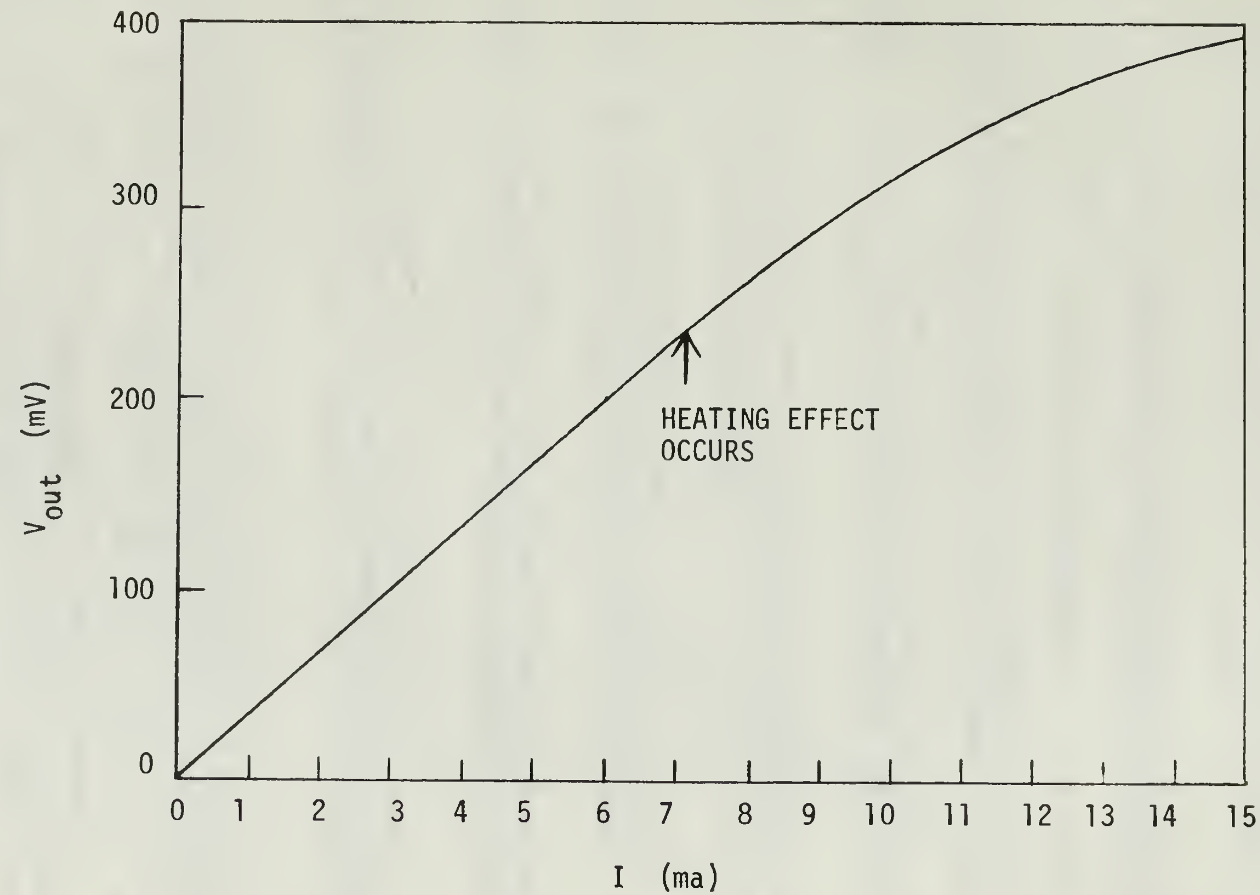

FIG. 16. HEATING EFFECT

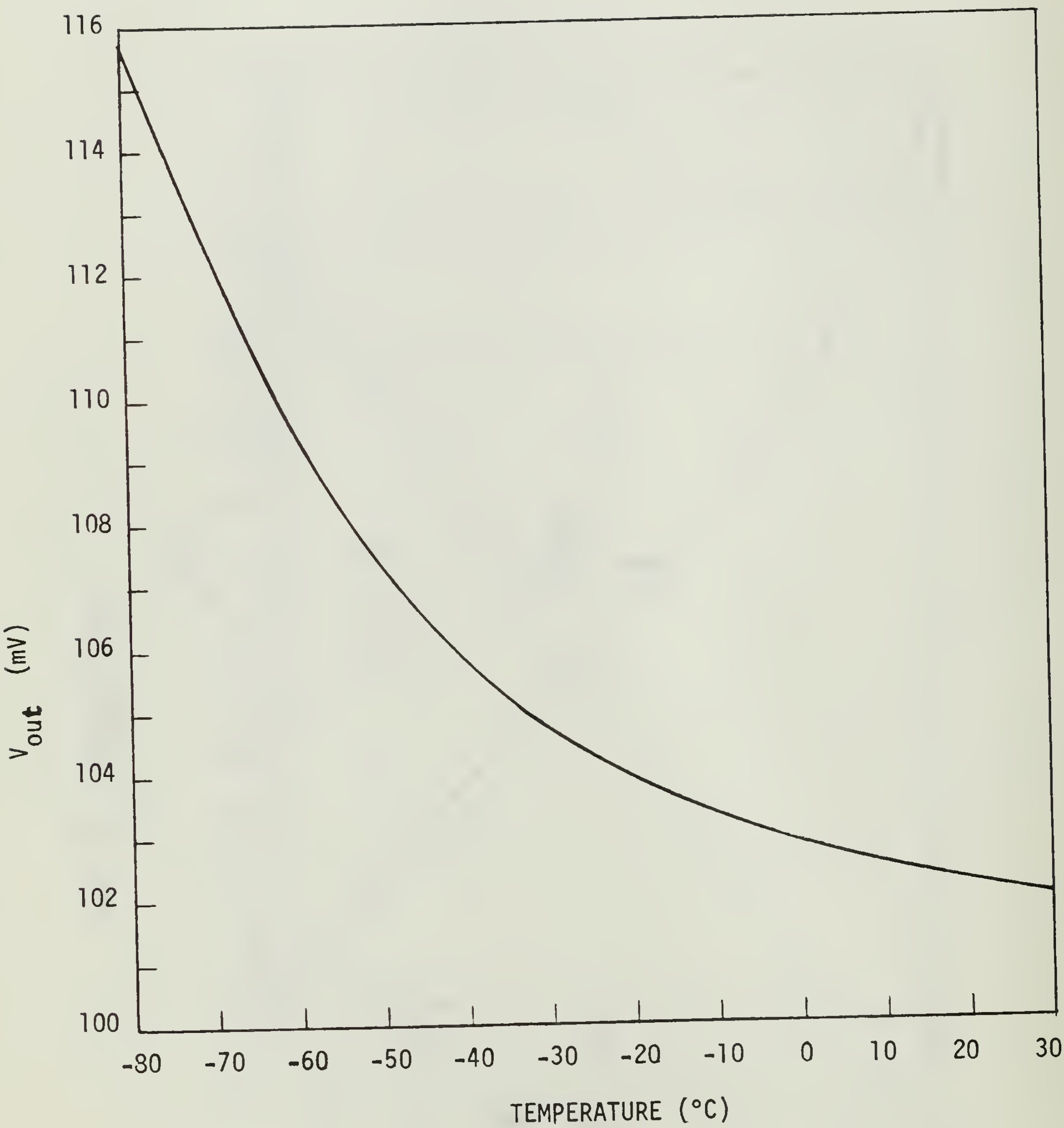

FIG. 17. TEMPERATURE EFFECT AT ONE ATMOSPHERE

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13. ABSTRACT

Current Navy expendable radiosonde sensors do not meet the required accuracies. A study was conducted to find improved sensors for temperature, pressure and humidity. Recent developments were investigated and recommendations made. An evaluation was conducted on a new humidity sensor and a new pressure sensor. The results obtained indicate improvements but further development is required.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Sensors						
Pressure						
Temperature						
Humidity						